AD-A047 877 WASHINGTON UNIV SEATTLE COLL OF ENGINEERING F/G 11/6
THE INFLUENCE OF MATERIAL DEFECTS ON DYNAMIC FRACTURE.(U)
NOV 77 I M FYFE, D H POLONIS DAAG29-74-G-0108
UNCLASSIFIED ARO-11956.4-MS NL

| OF |
AD
A047877

END
DATE
FILMED
1 -78
DDC

ARO 11956.4-MS

ADA047877

THE INFLUENCE OF MATERIAL DEFECTS ON DYNAMIC FRACTURE

FINAL REPORT

I. M. FYFE AND D. H. POLONIS

NOVEMBER 1977

U. S. ARMY RESEARCH OFFICE

GRANT DAAG29-74-G-0108

COLLEGE OF ENGINEERING
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER
DAAG29-74-G0108

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
rept.

4. TITLE (and Subtitle)
6 THE INFLUENCE OF MATERIAL DEFECTS ON DYNAMIC FRACTURE.

5. TYPE OF REPORT & PERIOD COVERED
9 Final, Feb [redacted] 74-Aug [redacted] 1977

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Ian M. Fyfe [redacted] Douglas H. Polonis

8. CONTRACT OR GRANT NUMBER(s)
15 DAAG29-74-G0108 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS
College of Engineering
University of Washington
Seattle, Washington 98195

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709

12. REPORT DATE
11 November 1977

13. NUMBER OF PAGES
10

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
18 ARO
N.A.
19 11956.4-MS

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N.A.

16. DISTRIBUTION STATEMENT (of this Report)
12 13p.

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N.A.

18. SUPPLEMENTARY NOTES
The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dynamic Fracture	Micro-cracking
Fracture Mechanics	Spallation
Fracture Morphology	Stress Waves

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An examination of dynamic fracture in iron, low carbon steel and high purity Al-Cu-Mg alloy under biaxial strain conditions showed that in Ferrovac E iron and high purity alloys, dynamic fracture is associated with intergranular failure. In commercial alloys, however, dynamic fracture occurs by void generation at brittle second phase impurity particles, and the subsequent void interconnection.
Static and dynamic tests on thin walled cylinders indicate that dynamic (cont.) over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

370 250

LB

20. pre-straining has negligible effect on the strain at failure in 6061-T4 aluminum, but reduces the failure strain in copper, the latter result possibly due to the increased yield strength caused by dynamic loading. In specimens dynamically loaded to failure plastic instability occured at the same strain value as that of the static case.

ACCESSION for		
NTIS	White Section	X
DDC	Buff Section	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CODES		
Dist.	AVAIL. and/or SPECIAL	
A		

Problem Statement

The ability to predict the ductile failure of materials subjected to high strain rate deformation is limited at present by the lack of understanding of the underlying mechanism or combination of mechanisms that account for the initiation of fracture. Earlier studies have pointed to the importance of void formation and decohesion on the fracture process. One of the problems considered in this project was to determine the influence of alloy purity and metallurgical parameters such as grain size and precipitation processes on the initiation of internal voids or cracks. The other aspect of the program relates to the incorporation of information about the microscopic initiation process, into a continuum model that could be used to predict the onset of failure when either a stress or strain history was determined for the material. The work carried out in this project therefore combined approaches embracing both the continuum and metallurgical aspects of the fracture process.

Approach

The specimens used in the experimental part of this project were of two distinct types. In the metallurgical study the specimens were thick hollow cylinders, while in the continuum study thin walled tubes or cylinders were employed. In each case the loading mechanism was an exploding wire system.

The experimental techniques used in the loading of the thick cylinders were developed in earlier studies,[1] and the geometry was such that by

[1] Schmidt, R. M. and Fyfe, I. M., "An Examination of Dynamic Fracture Under Biaxial Strain Conditions," Exper. Mech., 13(4): 163, April 1973.

varying the thickness of the cylinder wall, the stress history in the specimen could be controlled. In this way it was usually possible to create either a spallation type fracture in which the fracture surface was concentric to the axis of the specimen at a constant radius, or a fracture pattern composed of radial cracks. A variety of iron-base materials and precipitation hardenable aluminum-base alloys were studied using optical and scanning electron microscopy to examine the influence of microstructural features on the fracture mechanism.

The thin cylinder continuum tests were designed as part of this study to provide a simple plane stress condition under either dynamic or static loading. To achieve this the thickness of the specimen was matched to the rise-time of the loading pulse to prevent tensile stresses through the thickness of the specimen. The purpose of these tests were to provide information needed in an analysis of the stress field just prior to fracture under dynamic conditions. In particular, the necessary parameters required were, the time to failure, the stress loading history of the material, and possible strain rate dependency of the fracture process. The experimental techniques used in these studies are described elsewhere.[2] The analysis of the experiments were carried out with a plane stress finite-element elastic/viscoplastic program whose input was the stress history supplied from the experiments. The type of initiation mechanism used was obtained from the metallurgical studies.

---

[2]Fyfe, I. M., "The Influence of Strain Rate on Dynamic Loading," Proceedings 2nd International Conference on Mechanical Behavior of Materials, Boston, 1976.

Results

The dynamic fracture of iron and low carbon steels has been found to depend on purity, grain size, and the presence of brittle second phase particles. The fracture of Ferrovac E iron specimens is characterized by predominanatly intergranular microcracks for grain sizes over the range from 40 to 200 microns. In contrast to this behavior predominantly transgranular microcracks were observed to initiate at carbide particles and inclusions in 0.2% carbon steel of varying microstructure; specimen failure under these conditions occurs by a radial cleavage fracture mode rather than by the generation of voids leading to the process of spallation. The susceptibility to dynamic fracture increases with increasing grain size in 0.2% carbon steel exhibiting ferrite-pearlite microstructures. The contrasting intergranular cracking behavior in Ferrovac E iron results in brittle behavior leading to complete fragmentation under dynamic loading conditions, whereas extensive ductility is observed in the same material during slow tensile testing. The intergranular failure in Ferrovac E has been attributed to chronium-rich and nickel-rich inclusions at the boundaries and to thin, discontinuous films of grain boundary cementite which were detected on some of the fracture surfaces; it is therefore suggested that the segregation of trace impurities accounts for the intergranular fracture mode.

Armco iron cylinders exhibit a radial fracture mode that has been identified with the sensitivity of this material to stress intensification at internal flaws associated with nonmetallic inclusions. Armco exhibits limited void generation due primarily to interphase decohesion between MnS

inclusions and the ferrite matrix. The low density of such voids and the limited capability of the matrix for localized shear deformation preclude the void interconnection necessary for spall fracture. The failure process is primarily cleavage fracture proceeding in the radial and longitudinal directions. The elongation and the flattening of sulphide inclusions during hot working leads to the formation of sharp, cusp-shaped voids at the tips of the inclusions. These cusps can act as points of stress intensification for the initiation of crack propagation, particularly at particles where void formation is also occurring. The results indicate that the fracture behavior of materials having limited capacity for plastic flow under dynamic conditions, such as Armco iron and low carbon steels, is controlled by cleavage crack propagation rather than by void nucleation and interconnection.

Dynamic experiments were also conducted on a high purity Al-Cu-Mg alloy in which the concentration of these elements corresponded to the commercial 2024 alloy composition. The high purity alloy was relatively free from the inclusions, and brittle second phase impurity particles that account for the origin of microvoids during the dynamic loading of commercial aluminum alloys. Microvoid initiation and the process of spallation are confined almost exclusively to grain boundary sites in the high purity alloy. Mocrostructural studies involving optical and scanning electron microscopy techniques have revealed the occurrence of intergranular sliding and shear in the matrix adjacent to the fracture surface. The extensive flow observed in conjunction with the grain boundary void configurations points to the importance of localized shear as the most plausible mechanism for void interconnection

leading to spall fracture. The predominace of intergranular fracture results in a "jagged" spall pattern rather than a well-defined spall surface. These studies showed that any significant differences in the dynamic fracture behavior between solution treated alloys and those that have been aged to either peak hardness or the overaged condition are overshadowed by the predominace of grain boundary fracture. The fact that the initiation of voids was confined to the grain boundary regions has been interpreted as an indication that spallation failure is nucleation controlled where the material is relatively free from the brittle second phase particles essential for the initiation of voids at sites within the grains.

Th[illegible]tinuum study examined the failure of thin cylinders under both [illegible] and dynamic loading conditions by conducting a series of tests in which the strain at failure was measured. The measured strain value was the hoop strain in the cylinder some distance from an artifically induced flaw in the specimen, and failure was defined as the condition in which the specimens could no longer support any internal fluid pressure. A comparison of the strain at failure between the static and dynamic tests showed that the strain at failure in the dynamic case was considerably greater in both aluminum and copper specimens (see Ref. 2). Subsequent tests at different strain rates showed only a slight decrease in the ratio between the dynamic and static strains with lower strain rate levels. An additional series of tests were designed in which the specimens were loaded partially at a high strain rate, and then to failure under quasi-static loading conditions. These results are presented in Figs. 1 and 2. From these tests it can be seen that if the dynamically induced plastic pre-strain

was less than the strain at failure under static conditions subsequently static loading resulted in failure at approximately the same strain as for the purely static tests. However, if the dynamic loading resulted in plastic pre-strain somewhat greater than the failure strain which occurs under purely static loading, the cylinder did not fail. The subsequent static portion of the test required that the load be sufficient to cause the cylinder to again reach the yield stress. It was also observed from these tests that, regardless of the loading rate, plastic instability occurred in the vicinity of the flaw at approximately the same strain level.

From the above tests it can be concluded that although the results presented in Ref. 2, and in other reports related to dynamic fracture are essentially correct, they can be misleading as to the role played by strain rate on the fracture process. If failure is redefined as the onset of plastic instability in the vicinity of the flaw, then the differences between static and high strain rate loading ($\dot{e} \approx 1 \times 10^4$ sec^{-1}) to failure are greatly reduced. Variations in the yield stress and strain values at failure, evident in Figs. 1 and 2, could be due to either loading path differences between the static and dynamic tests, or the strain rate dependency of the material. As both of these are not necessarily connected to the failure process, they do not alter the conclusion reached above, but do play important roles in dynamic fracture analysis. It is suggested that differences in the loading path between the static and dynamic tests could be eliminated by using ring specimens to replace the thin cylinders.

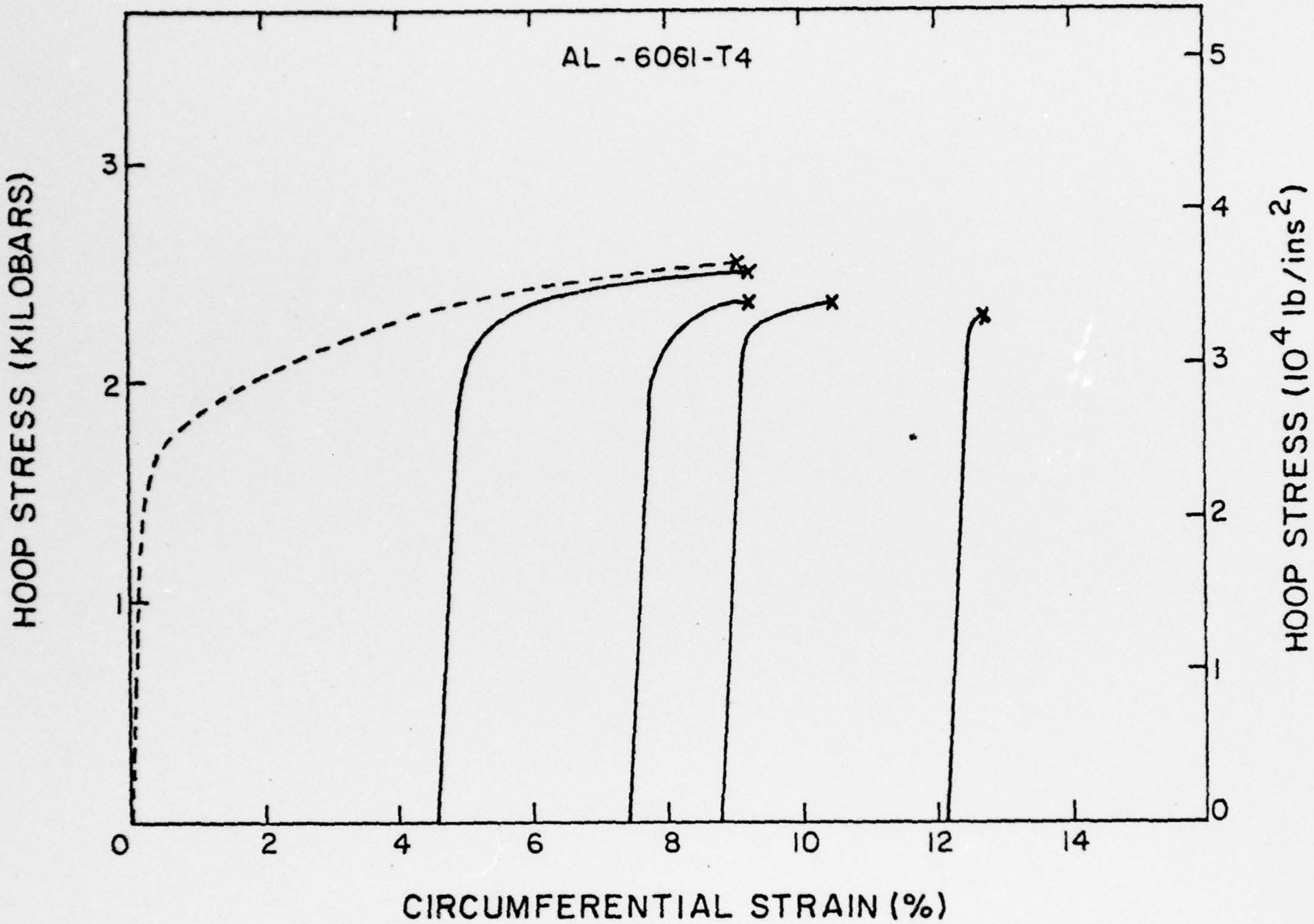

Fig. 1 Static Pressure Loading to Failure of Thin Walled Aluminum Cylinders: -----x static only; ——x dynamic prestrain

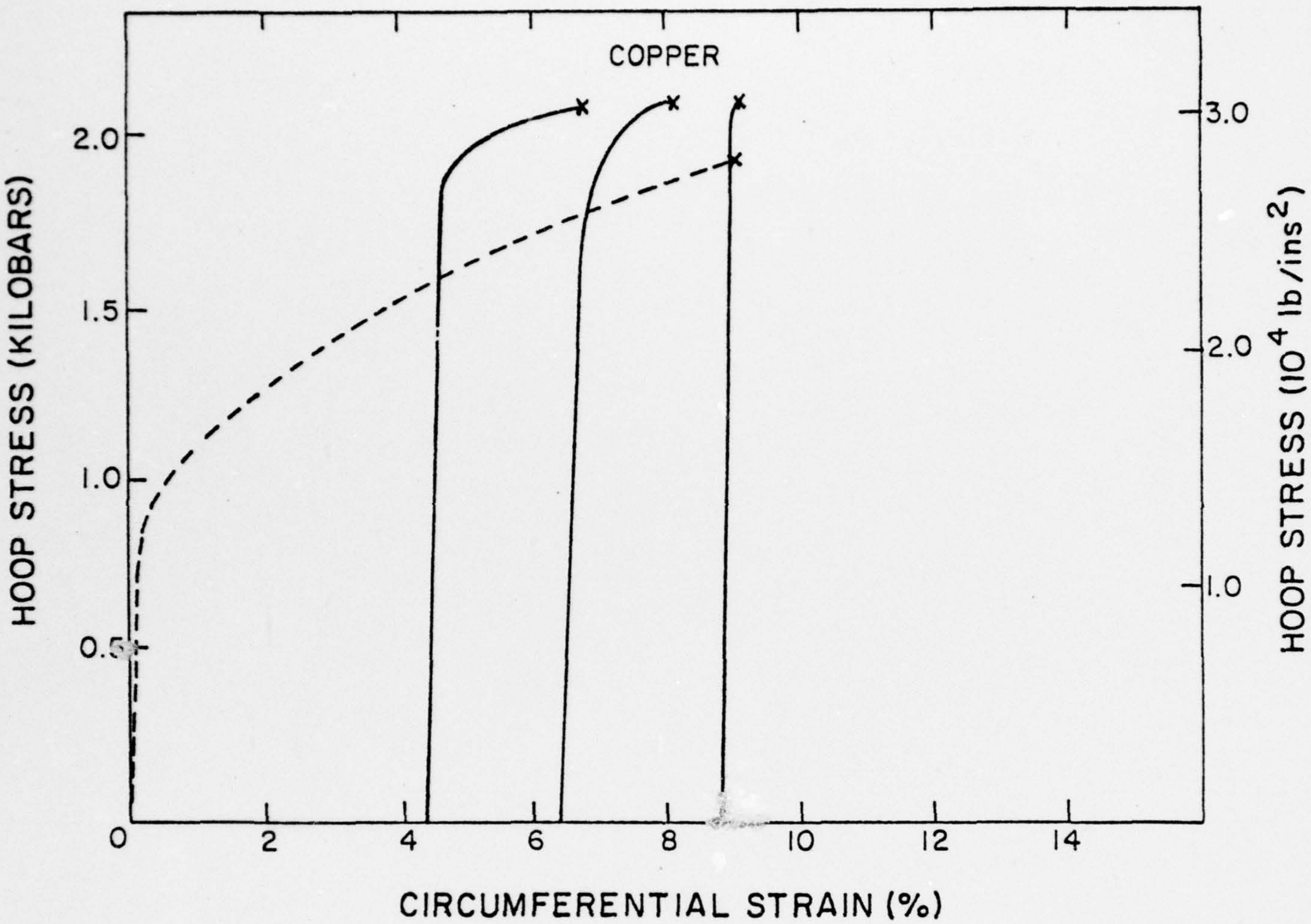

Fig. 2 Static Pressure Loading to Failure of Thin Walled Annealed Copper Cylinders: ----x static only; ——x dynamic prestrain

Publications and Reports

"An Investigation of a Possible Technique to Examine Dynamic Failure," M.S. Thesis (M. Kirk), June 1974.

"The Applicability of Elastic/Viscoplastic Theory in Stress Wave Propagation," Journal of Applied Mechanics, 42(1): 141, 1975.

"Microstructural Origins of Dynamic Fracture in 2024 Aluminum Alloy," Metallography, 8: 425, 1975.

"Influence of Microstructural Features on the Dynamic Fracture Behavior of Some Iron Base Materials," Material Science and Engineering, 22: 51, 1976.

"The Influence of Strain Rate on Dynamic Fracture," Proceedings 2nd International Conference on Mechanical Behavior of Materials, 1458, 1976.

Participating Scientific Personnel

The following personnel were associated with this project for varying lengths of time during the course of the grant.

Name	Position	Degree Awarded
Dr. I. M. Fyfe	Principal Investigator	----
Dr. D. H. Polonis	Principal Investigator	----
Dr. H. Vora	Research Associate	----
M. Kirk	M.S. Candidate	7/74
A. Deleo	M.S. Candidate	6/75
F. Horey	M.S. Candidate	6/76
T. Mathis	M.S. Candidate	----
A. M. Rajendran	Ph.D. Candidate	----